Stratospheric Ozone Assessment

Appendix G

Introduction

This appendix describes the assessment of costs and benefits of Title VI of the Clean Air Act Amendments (CAAA). Provisions under Title VI limit emissions of stratospheric ozone-depleting chemicals. Cost and benefit estimates of Title VI provisions are derived from a secondary analysis that updates key economic valuation components of previous analyses conducted by EPA's Office of Air and Radiation, Stratospheric Protection Division. We chose to perform a secondary analysis for several reasons: (1) prior analyses suggest that the benefits of these programs far exceed the costs, suggesting a potentially low value of information from re-estimating costs and benefits in new primary analyses; (2) prior analyses were extensively peer-reviewed; (3) the costs and benefits of these provisions are largely separable from provisions implemented under other titles of the Clean Air Act Amendments; and (4) developing new primary estimates would involve considerable time and expense. We therefore provide a new assessment of the valuation of benefits to ensure consistency with other portions of the prospective analysis, but have not re-assessed the Agency's previous estimates of stratospheric ozone depleter emissions, stratospheric ozone loss, changes in exposure to UV-b radiation, changes in physical effects, or the costs of Title VI provisions.

Unlike estimates for other Titles of the CAAA, we present estimates for Title VI as net present values of the streams of annual costs and benefits. The rationale for this type of presentation of costs and benefits relates to the long-term nature of the mechanisms of stratospheric ozone depletion and measures taken to avoid depletion. Stratospheric ozone is a global resource, and its formation and depletion are governed by long-term processes that may take place over decadal or longer time scales. Attempting to parse the incremental effects of an annual reduction in emissions of ozone depleting substances and estimate its impact at the unit emissions level is an extremely difficult, if not impossible, task and was not attempted for this exercise.

For the same reasons, We conduct a longer time-scale of analysis than is used in the remainder of the study. We estimate cost over the period 1990 through 2075, and benefits are estimated over the period 1990 to 2175. The difference in time scales for costs and benefits reflects the persistence of ozone depleting substances in the atmosphere, the slow processes of ozone formation and depletion, and lags in the manifestation of physical effects in response to exposure to elevated levels of UV-b radiation. The full benefits of emissions reductions achieved during 1990 to 2075 accrue across many decades and several generations, requiring an extended time scale for benefits analysis.

In the next section of the appendix, we provide a brief history of Title VI and its amendments. Next we summarize the general approaches used to estimate the costs and benefits in previous analyses, and we describe our strategy for modifying several analytical parameters to ensure consistency with the assessments of other titles of the Clean Air Act. Finally, we present the adjusted cost and benefits from 1990 to 2165 and discuss the uncertainty associated with the analyses.

History of Stratospheric Ozone Protection and the CAAA

The protection of stratospheric ozone is an international effort, resulting in several multinational agreements. The United States has both participated in the development of these international agreements and has created its own reduction and phaseout schedules for ozone-depleting substances used within its borders. These reduction and phaseout schedules, codified under Title VI of the Clean Air Act Amendments, are often stricter than the international agreements that preceded them. Below we briefly describe the history of the international agreements and their relationship to the Clean Air Act Amendments.

The United States, the European Economic Community, and 23 other countries signed the "Montreal Protocol on Substances that Deplete the Ozone Layer" (1987 Montreal Protocol) on September 16, 1987. Thirty-four countries then ratified this protocol. The agreement prohibits the use of chlorofluorocarbons (CFCs) beyond 1986 usage levels starting in mid-1989 and establishes a schedule for reducing the production of CFCs (i.e., a 20 percent reduction in CFC production in 1993 and a 50 percent reduction in 1998). The protocol also forbids the production of halons beyond 1986 production levels starting in 1992. On August 12, 1988, the U.S. Environmental Protection Agency (EPA) published final regulations to protect stratospheric ozone and comply with the requirements of the 1987 Montreal Protocol.[1]

After ratification of the Montreal Protocol scientists determined that the loss of stratospheric ozone was greater than they had originally thought and that man-made compounds containing bromine and chlorine were responsible for this loss. Consequently, in June 1990 the countries that had signed the Montreal Protocol met in London to develop an accelerated CFC reduction schedule (i.e., a decrease in CFC production to 50 percent of 1986 production levels by 1995 and 15 percent of 1986 levels by 1997). According to this London Agreement, production of CFCs, halons, and carbon tetrachloride will cease by 2000 and methyl chloroform (MCF) production would end by 2005.[2]

In November 1990 President George Bush signed the Clean Air Act Amendments (CAAA), which include Title VI. This title consists of six major sections, of which the most important are sections 604 and 606. Section 604 accelerates the London Agreement's reduction schedules for CFCs, halons, and carbon tetrachloride and shortens the time allowed for methyl chloroform phaseout by three years. Section 606 allows Congress to accelerate the reduction and phaseout schedules of section 604 if necessary to protect human health and the environment. Together, sections 604 and 606 generate nearly all of the costs and benefits of Title VI. The remaining sections include the following: section 608 (which requires the EPA to establish standards regarding the use and disposal of ozone-depleting substances during the service, repair, or disposal of appliances and industrial refrigerators); section 609 (which requires the EPA to regulate the servicing of motor vehicle air conditioners); and section 611 (which stipulates that the EPA must establish labeling requirements for containers of ozone-depleting substances and for products containing these substances). This analysis does not examine the costs and benefits of section 605, which institutes the reduction and phaseout schedules for hydrochlorofluorocarbons (HCFCs), because the schedules of section 606 supersede section 605's timetables. Table G-1 provides a description of the principal sections of the CAAA's Title VI.

[1] ICF, Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals,* Prepared for Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, D.C., July 1, 1992, page ES-1.

[2] Ibid, ES-1 and ES-2.

Table G-1
Six Major Sections of Title VI

Section	Description
Section 604 - Class I Phaseout	Institutes the reduction and phaseout schedules for Class I substances (methyl chloroform, halons, chlorofluorocarbons, carbon tetrachloride).
Section 605 - Class II Phaseout	Institutes the reduction and phaseout schedules for Class II substances (hydrochlorofluorocarbons).
Section 606 - Accelerated Schedule	Permits Congress to accelerate the phaseout schedule of Class I and II substances if necessary for the protection of human health and the environment. Also, if countries modify the Montreal Protocol to accelerate phaseout schedules of Class I and II chemicals, Congress can amend the Clean Air Act to reflect these modifications.
Section 608 - National Recycling and Emission Reduction Program	Requires the EPA to establish standards regarding the use and disposal of Class I and II substances during the service, repair, or disposal of appliances and industrial refrigeration units.
Section 609 - Servicing of Motor Vehicle Air Conditioners	Requires the EPA to regulate the servicing of motor vehicle air conditioners.
Section 611 - Labeling	Stipulates that the EPA establish labeling requirements for containers of Class I and II substances and for products containing these substances.

In November 1992 the parties to the Montreal Protocol met in Copenhagen to establish an agreement that incorporates new scientific information on stratospheric ozone depletion.[3] For example, data from the National Aeronautics and Space Administration (NASA) indicated that ozone depletion was progressing more rapidly than expected. In addition, ozone depletion was extending further south in the United States than anticipated and lasting longer (late fall to late May).[4] In response to new data, the parties to the Montreal Protocol agreed to several changes in the reduction and phaseout schedules of ozone-depleting chemicals. First, they agreed to a 1999 phaseout deadline for hydrobromofluorocarbons (HBFCs), chemicals not regulated under the earlier London Agreement. Second, they called for a freeze on production of methyl bromide by stipulating that the chemical should not exceed 1991 levels starting in 1995.[5] Third, these countries decided to accelerate the reduction schedule for the production and consumption of hydrochlorofluorocarbons (HCFCs). Lastly, they hastened the phaseout of halons by agreeing to 1994 as the production and consumption phaseout deadline.[6]

[3] U.S. Environmental Protection Agency, http://www.epa.gov/ttn/oarpg/t6/fact_sheets/66.txt, March 25, 1998.

[4] Ibid, ES-3 and ES-4.

[5] U.S. Environmental Protection Agency, http://www.epa.gov/spdpublc/mbr/harmoniz.html, March 26, 1999.

[6] U.S. Environmental Protection Agency, http://www.epa.gov/ttn/oarpg/t6/fact_sheets/66.txt, March 25, 1998.

Under the Clean Air Act Amendments' section 606, the EPA also responded to the new scientific data by periodically accelerating the reduction schedules for MCF, CFCs, halons, carbon tetrachloride, and HCFs and by establishing earlier phaseout deadlines. In addition, the EPA targeted HBFCs and methyl bromide, chemicals not explicitly addressed by the 1990 Clean Air Act Amendments.

The most recent changes established under section 606 involve methyl bromide. In 1993 the EPA called for a freeze on production at 1991 levels starting in 1994 and established a phaseout deadline of 2001. In 1995 and 1997 the parties to the Montreal Protocol met in Vienna and Montreal, respectively, to address issues such as the phaseout of methyl bromide. In 1998 Congress directed the EPA to match the 1997 Montreal Amendment's reduction and phaseout schedule for this chemical. In 1998, Congress amended the Clean Air Act to establish a new methyl bromide reduction schedule, which establishes 2005 as the phaseout deadline, and helps to address the needs of American farmers who are currently waiting for methyl bromide alternatives that are in the research and development stage.[7] Table G-2 presents the most significant sections of the new and old phaseout schedules.

[7] U.S. Environmental Protection Agency, http://www.epa.gov/spdpublc/mbr/harmoniz.html, November 9, 1999.

Table G-2
Phaseout Scenario in Clean Air Act Section 604 and
Phaseout Scenario in Amendments Added under Clean Air Act Section 606

Year	Section 604 (Original Schedule)		Section 606 (Revisions to Original Schedule)
1991	• Methyl chloroform (MCF) production decreases to 1989 levels		
1993	• MCF production decreases 10% from 1989 levels		
1994	• MCF production decreases 15% from 1989 levels	➜	• MCF production decreases from 1989 levels by 50%
1995	• MCF production decreases 30% from 1989 levels	➜	• MCF production decreases from 1989 levels by 70%
1996	• MCF production decreases 50% from 1989 levels	➜	• 100% phaseout of MCF
2000	• MCF production decreases 80% from 1989 levels		
2002	• 100% phaseout of MCF		
1989	• Chlorofluorocarbon (CFC) production decreases to 1986 levels		
1991	• CFC production decreases 15% from 1986 levels		
1992	• CFC production decreases 20% from 1986 levels		
1993	• CFC production decreases 25% from 1986 levels		
1994	• CFC production decreases 35% from 1986 levels	➜	• CFC production decreases to 75% from 1986 levels
1995	• CFC production decreases 50% from 1986 levels	➜	• CFC production decreases to 75% from 1986 levels
1996	• CFC production decreases 60% from 1986 levels	➜	• 100% phaseout of CFC production
1997	• CFC production decreases 85% from 1986 levels		
2000	• 100% phaseout of CFC production		

Year	Section 604 (Original Schedule)		Section 606 (Revisions to Original Schedule)
1991	• Halon production decreases 15% from 1986 levels		
1992	• Halon production decreases 20% from 1986 levels		
1993	• Halon production decreases 25% from 1986 levels		
1994	• Halon production decreases 35% from 1986 levels	➜	• 100% phaseout of halons
1995	• Halon production decreases 50% from 1986 levels		
1996	• Halon production decreases 60% from 1986 levels		
1997	• Halon production decreases 85% from 1986 levels		
2000	• 100% phaseout of halon production		
1991	• Carbon tetrachloride production decreases to 1989 levels		
1992	• Carbon tetrachloride production decreases 10% from 1989 levels		
1993	• Carbon tetrachloride production decreases 20% from 1989 levels		
1994	• Carbon tetrachloride production decreases 30% from 1989 levels	➜	• Carbon tetrachloride production decreases 50% from 1989 levels
1995	• Carbon tetrachloride production decreases 85% from 1989 levels	➜	• Carbon tetrachloride production decreases 85% from 1989 levels
1996		➜	• Carbon tetrachloride production decreases 100% phaseout of carbon tetrachloride
2000	• 100% phaseout of carbon tetrachloride		

Year	Section 604 (Original Schedule)		Section 606 (Revisions to Original Schedule)
1994			• Freeze on production and consumption of methyl bromide at 1991 levels
1999			• 25% phaseout of methyl bromide
2001			• 50% phaseout of methyl bromide
2003			• 75% phaseout of methyl bromide
2005			• 100% phaseout of methyl bromide
			(quarantine and preshipment uses exempt; critical agriculture uses allocated after 2005)
1996			• 100% phaseout of hydrobromofluorocarbons (HBFCs)
2003		➜	• Production and consumption of HCFC-141b banned
2010		➜	• Production and consumption of HCFC-142b and HCFC-22 decreases to 1989 levels
(2010-2020)		➜	• Production and consumption of HCFC-142b and HCFC-22 permissible only for servicing equipment manufactured prior to 2010
2015	• Freeze on HCFC production	➜	• Production and consumption of the remaining HCFCs decreases to 1989 levels
2020		➜	• 100% phasout of HCFC-142b and HCFC-22
2030	• Prohibition of HCFC production after January 1, 2030	➜	• 100% phaseout of the final category of HCFCs

Cost and Benefit Approaches

To estimate the costs and benefits of Title VI, we rely primarily on past EPA regulatory impact assessments (RIAs), including the following:

- *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs* (1993);

- *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals* (1992);

- *Regulatory Impact Analysis: The National Recycling and Emission Reduction Program (Section 608 of the Clean Air Amendments of 1990)* (1993);

- *Section 609 of the 1990 Clean Air Act: Refrigerant Recycling for Mobile Air Conditioners: Cost-Benefit Analysis and Regulatory Flexibility Analysis* (1991);

- *Draft: Regulatory Impact Analysis of the Proposed Rule Requiring Labeling of Products Containing or Manufactured with Ozone Depleting Substances* (1991).

The major difference between this analysis and the RIA analyses involves the parameters used to value the costs and benefits. To ensure consistency with the larger Section 812 analysis, we adjust the discount rate in the costs calculations, and we adjust the value of statistical life, GDP per capita growth rates, and the discount rate in the benefits calculations.

Cost Approach in RIAs

Existing regulatory impact assessments (RIAs) for individual provisions of Title VI provide the basis for the social costs of phasing out CFCs, halons, methyl chloroform, and HCFCs.[8] These social costs are the additional quantities of resources necessary to produce equivalent quantities of goods and services for consumers. To generate social cost estimates, the RIAs calculate the costs of replacing ozone-depleting chemicals (ODSs) with alternative technologies and materials, as well as the costs of recycling and storing unused ODSs. The estimates also include costs of training, labeling, and administration. The total cost estimate of Title VI comprises the costs of sections 604 and 606 and the incremental costs of the remaining sections (i.e., the cost estimates for sections 608, 609, and 611 do not include the costs of actions already required by sections 604 and 606). Table G-3 indicates the major costs associated with each section. We present summaries of the cost methodologies in this appendix; for more details, see the RIAs of the individual provisions of Title VI.

[8] Only a small percentage of carbon tetrachloride (less than three percent of the total produced in the U.S.) is subject to the CAAA, and the costs of phasing out carbon tetrachloride are likely insignificant compared to the costs of phasing out CFCs, halons, and MCFs. Consequently, the RIAs do not quantify the costs of phasing out carbon tetrachloride. In addition, this analysis does not assess the cost of methyl bromide because *Part 2: The Cost and Cost-Effectiveness of the Proposed Phaseout of Methyl Bromide* does not provide the corresponding benefits.

Table G-3
Scope of Title VI Cost Estimates

Section	Costs
604 & 606	• Capital investment and variable costs associated with switching to alternative technologies and non-ozone-depleting substances; • Possible elimination of products containing ozone-depleting substances (ODSs) if firms are unable to develop cost-effective manufacturing alternatives; • Costs of recycling ODSs; • Additional costs of switching from methyl bromide to other substances (e.g. purchases of more costly substitutes, incremental labor needs, and crop and throughput issues).
608	• Purchase of ODS recovery equipment; • Training and certification of technicians; • Filtration of refrigerants to remove impurities; • Leak repair requirements; • Storage of unused chlorofluorocarbons (CFCs); • Paperwork.
609	• Training and certification of mobile air conditioner (MAC) service technicians; • Recycling costs, including fees for off-site recycling or labor and capital costs for on-site recycling.
611	• Development and application of new labels; • Administrative activities associated with compliance; • Possible accelerated substitution of less harmful substances relative to the mandates of the rule codifying the phaseout of ODSs (thereby resulting in additional costs beyond those resulting from the phaseout rule).

Costs: Sections 604 and 606

To generate the costs of section 604, the *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs* (1993) and the *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals* (1992) use engineering analyses that involve several steps. First, the RIAs identify potential technical responses to section 604 from 1990 to 2075. For example, they examine data on the CFC reduction technologies available to each CFC-using industry (i.e., mobile air conditioners, household refrigeration, foam blowing, solvent cleaning, sterilization, rigid polyurethane foams, chillers, and process-12 refineries).[9] For halon the RIAs analyze 74 categories of fire extinguishing applications, the primary users of the substance.[10] With these data, the RIAs identify three potential technical responses: use of chemical substitutes for CFC and halon use in new and existing equipment, implementation of engineering controls that reduce use of ODSs through recycling, and use of product substitutes for ODS-containing products.

Second, the RIAs assess the costs of the responses. For halons and CFCs the RIAs examine the date at which an action is first available for adoption, the time necessary for the entire industry to evaluate the action, and the time required for

[9] ICF, Incorporated, *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs*, Prepared for the Stratospheric Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency, September 10, 1993, page 6.

[10] ICF, Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals,* Prepared for Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, July 1, 1992; page 4-7.

firms to adopt the action if it is cost-effective. They also study reduction potential (decrease in ODS use for all firms that have decided to take the action) and applicability to new and/or existing equipment. This CFC and halon cost approach is similar to the approach used in the U.S. Environmental Protection Agency's *Regulatory Impact Analysis: Protection of Stratospheric Ozone* (1988); the main difference is the expansion of the methods used to model the lifetimes of equipment using CFC and halons.[11] By contrast, for MCFs the RIAs do not focus on the lifetime of the equipment because firms can retrofit MCF-consuming end uses with MCF alternatives.[12] Using the relevant data for MCFs, halons, and CFCs, the RIAs estimate feasible schedules for implementation of reduction measures and estimate the following costs:

- Variable costs (e.g., materials, energy, labor, and operating expenses);
- Capital costs;
- One-time fixed costs (e.g., research and development or training); and
- Changes in energy efficiency.

For the last step of the cost analyses, the model selects technologies that minimize production cost increases and achieve the necessary ODS reductions. The final set of control plans must satisfy the following requirements: 1) the plans contain components that industry has already implemented or intends to implement in the near future; 2) they jointly ensure that the amount of CFC production over time does not exceed the maximum stipulated by the phaseout schedule; and 3) they collectively prevent CFC use after the phaseout deadline from exceeding feasible recycling.

Under section 606 the EPA accelerates the reduction and phaseout schedules of ODSs; for these substances the cost methodology is the same as the section 604 methodology for CFCs, halons, methyl chloroform, and carbon tetrachloride. For HCFCs the EPA calculates the costs of phaseout by multiplying the quantity of replaced HCFCs by the difference in price between the HCFC compound and its substitute. This analysis assumes that the replacement compounds will cost between 10 and 50 percent more than the HCFCs. Together, the costs of sections 604 and 606 are $55.9 billion (1990 dollars) with a two percent discount rate; these costs comprise nearly all of the costs of Title VI.

Costs: Sections 608

For section 608, the *Regulatory Impact Analysis: The National Recycling and Emission Reduction Program (Section 608 of the Clean Air Amendments of 1990)* (1993) uses the section 604 cost model to forecast the timing of emissions controls, resulting prices, and recycling levels from 1994 to 2015. In particular, the model assumes that recovery efficiency is 95 percent and predicts that all users of chillers, industrial processes, cold storage, retail food, and refrigerated transport will either recover

[11] Specifically, the cost model improves upon the 1988 model in the following ways: tracking the size, age, and turnover of CFC-consuming equipment over time; simulating the lifecycle of the equipment in terms of manufacturing, operation, servicing, and disposal; estimating CFC use, CFC emissions, energy use, and costs for each point in the lifecycle; calculating CFCs potentially available through recycling from older equipment; and simulating the impact of CFC reduction measures by assessing the degree of emissions reductions, total costs, and total changes in energy use associated with implementing groups of controls over time for each end use. (ICF Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals*, Prepared for the Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, 1992, pages 4-2, 4-8, 4-9, and 4-16.)

[12] The EPA's *Costs and Benefits of Phasing Out Production of CFCs and Halons in the United States* (1989) and the EPA's *Regulatory Impact Analysis: Protection of Stratospheric Ozone* (1988) provide the basis of the cost methodology for the MCF phaseout. Note that the MCF model calculates energy costs as a part of operating costs, rather than as a separate component, because MCF end uses are not energy intensive. (ICF Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals*, Prepared for the Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, 1992, pages ES-8, 4-27.)

or recycle CFCs at service and disposal and that after the phaseout all household appliance users will recover CFCs at disposal.[13] With a two percent discount rate the cost estimate is $1.2 billion (1990 dollars).

Costs: Section 609

Section 604 prompts service establishments to recycle CFC-12 in mobile air conditioners (MACs). Therefore, the section 604 cost estimate accounts for most costs associated with the recycling of CFC-12 from MACs. The costs of section 609 that are not included in the section 604 cost estimate are the costs of training and certifying MAC service technicians. The analysis of the social costs of Section 609 examines these costs from 1992 to 2008 under two scenarios: a lower bound scenario in which small and large shops recover CFC-12 and pay an off-site recycler to purify and return the used refrigerant and an upper bound scenario in which all shops recycle CFC-12 on-site.[14] The central cost estimate for section 609 with a two percent discount rate is $14.3 million (1990 dollars).

Costs: Section 611

For section 611, the *Draft: Regulatory Impact Analysis of the Proposed Rule Requiring Labeling of Products Containing or Manufactured with Ozone Depleting Substances* (1991) evaluates two response options: companies label all products or they reformulate/redesign the products to eliminate the use of Class I ozone-depleting substances (fully halogenated CFCs, three halons, methyl chloroform, and carbon tetrachloride).[15] The RIA then assesses three associated costs: costs of implementing substitutes (for MCF-containing products) more rapidly than predicted under the phaseout schedule, administrative activity costs, and costs of labeling.[16] From 1994 to 2000 the costs of section 611 are $252 million with a two percent discount rate.

Benefits Approach in RIAs

The RIAs' Title VI benefits analyses necessarily differ from the benefits analyses for other parts of our CAAA-analysis because, unlike most of the effects of criteria air pollutants, the effects of Title VI are global in scale and occur over several hundred years. The delay in effects occurs for several reasons. First, emissions often emanate from products that leak the ozone-depleting chemicals over a significant period of time. Second, ozone-depleting chemicals rise into the stratosphere and affect the ozone layer at a slow rate. Third, ozone-depleting substances can persist in the stratosphere for many years. Fourth, natural processes that replace stratospheric ozone are slow. To reflect the long time period during which stratospheric ozone depletion occurs, this analysis assumes that the benefits accrue from 1990 to 2165.

Figure G-1 is a simplified illustration of the relationships between the sets of data used in the existing benefits analyses. First, the EPA estimates change in ozone-depleting substance emissions. With these data the EPA calculates the extent of stratospheric ozone depletion and global warming. Then the EPA calculates the effects of stratospheric ozone on UV-b radiation, which in turn affects

[13] ICF, Incorporated, *Regulatory Impact Analysis: The National Recycling and Emission Reduction Program (Section 608 of the Clean Air Amendments of 1990)*, Prepared for the Stratospheric Protection Division, U.S. Environmental Protection Agency, March 25, 1993, page 4-2.

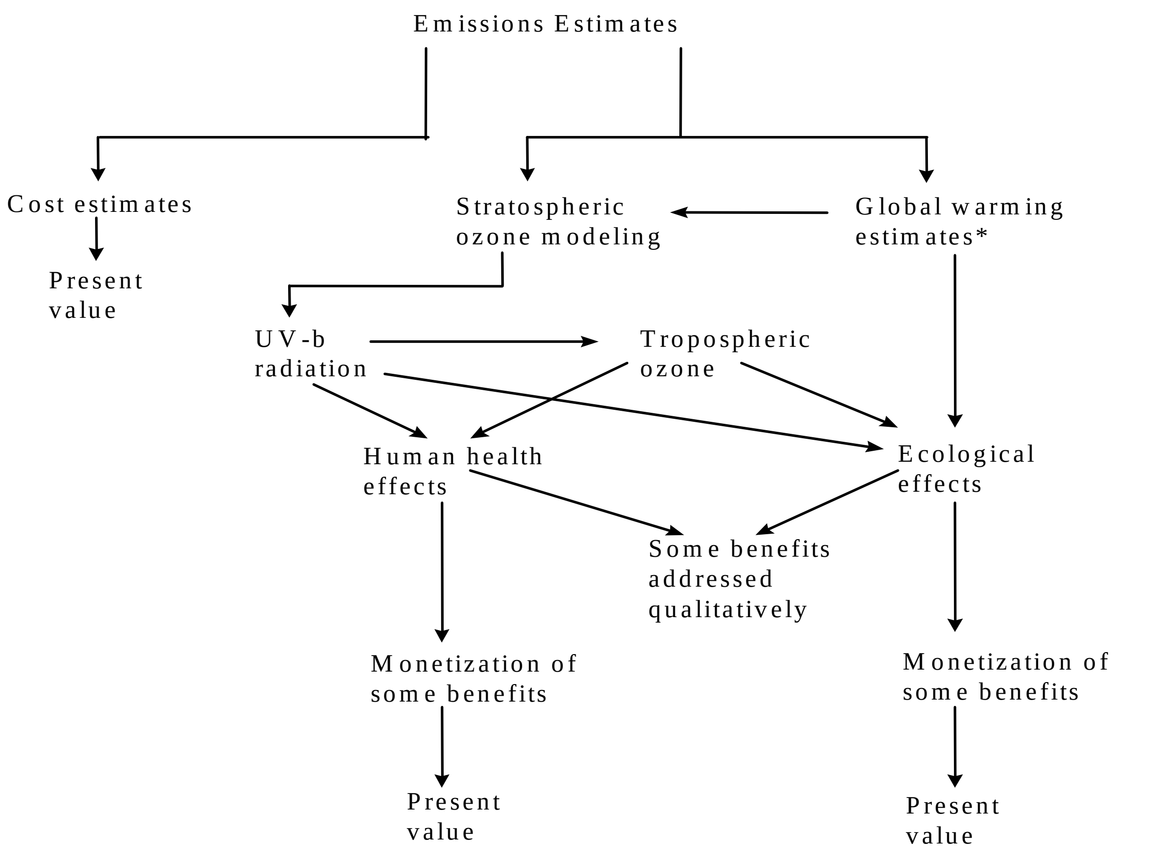
[14] ICF, Incorporated, *Section 609 of the 1990 Clean Air Act: Refrigerant Recycling for Mobile Air Conditioners: Cost-Benefit Analysis and Regulatory Flexibility Analysis*, Prepared for the Division of Global Change, U.S. Environmental Protection Agency, May 24, 1991, pages 4 and 8.

[15] The costs analysis does not account for the accelerated reduction and phaseout schedule of section 606. ICF, Incorporated, *Draft: Regulatory Impact Analysis of the Proposed Rule Requiring Labeling of Products Containing or Manufactured with Ozone Depleting Substances*, Prepared for Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, November 1991, pages 1, 4, and 6.

[16] *Ibid,* page 37.

Figure G-1

SCHEMATIC OF COST AND BENEFIT ANALYSES OF TITLE VI



* Several ozone-depleting substances are also greenhouse gases with high radiative forcing potential relative to carbon dioxide. We do not assess the impact of global warming in this analysis.

estimates of tropospheric ozone.[17] Using UV-b radiation, tropospheric ozone, and global warming data as inputs, the EPA estimates human health and environmental effects.[18] Lastly, the EPA monetizes the benefits of improved human and environmental health where possible.[19] In this analysis, our assessment of benefits is slightly different from that of the previous RIAs because we attribute benefits to effects of reduced stratospheric ozone and not to global warming. We present the benefits estimate as a net present value, rather than an annualized value, because annualization incorrectly imputes benefits of later phaseouts to earlier years. For example, annualization of the benefits of phasing out HCFC-22 by 2020 attributes benefits to years prior to 2030, when neither the costs nor the benefits of that phaseout have yet occurred. Consequently, an annualized estimate will overstate benefits at the beginning of the time span and understate them later.

Emissions Modeling

The methodology for predicting global use of ozone-depleting chemicals and the resulting emissions is similar to the methodology used in *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals* (1992). The main difference in the baseline scenario, which assumes no Title VI controls, involves methyl bromide. In this analysis we assume the following as a baseline: 1) in 1990 facilities worldwide produce 63 million kilograms of methyl bromide and facilities in the U.S. produce 29.1 million kilograms; 2) methyl bromide production grows at 5.5 percent annually until 2025 and zero percent thereafter; 3) 50 percent of methyl bromide production generates emissions; 4) humans generate about 25 percent of total methyl bromide emissions[20]; and 5) bromine is 40 times as effective as chlorine at destroying ozone. Also, based on NASA's new data regarding the extent of ozone depletion in the Northern Hemisphere, the model assumes that the weighted average ozone depletion was 3.38 percent in 1989 relative to 1979 . [21]

The control scenario used in this prospective analysis is based on the "CAA phaseout scenario" established in the 1992 RIA and the "President's schedule" outlined in *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFC's, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFC's* (1993). The phaseout schedule, presented in Table G-2, summarizes the emission reductions incorporated in this study's control scenario. The emissions model forecasts global use and emissions of CFCs, MCFs, carbon tetrachloride, HCFCs, and halons under the control scenario in two major steps.[22] For sections

[17] The relationships between stratospheric ozone depletion and global warming and between stratospheric ozone depletion and tropospheric ozone are incompletely understood at this time. The *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals* (1992) and the *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs* (1993) base their tropospheric ozone estimates on the "Effects of Increased UV Radiation on Urban Ozone" (Whitten and Gery, 1986).

[18] Note that the *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals* (1992) and the *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs* (1993) do not provide data on the models used to estimate UV-b radiation.

[19] The benefits estimates used in the RIAs' benefit/cost comparison sections do not reflect economic impacts (e.g., profit increases that occur if alternative technologies are more efficient than ODS-using technologies).

[20] Sources of methyl bromide include anthropogenic and natural sources. Natural sources include the ocean, plants, and soil.

[21] Stolarski, Watson, Testimony to the Senate Commerce, Science, and Transportation Subcommittee on Science, Technology, and Space, April 16, 1991; ICF, Incorporated, *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs*, Prepared for the Stratospheric Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency, September 10, 1993, page 9.

[22] See ICF, Incorporated, *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs*, Prepared for

reflecting the accelerated reduction and phaseout schedule, the model first applies the chemical demand growth rates developed for the *Regulatory Impact Analysis: Protection of Stratospheric Ozone* (1988), with the assumption that all nations will comply with the Copenhagen Amendments. For the other sections (i.e., section 611, section 609, and the ecological components of sections 604 and 606), the model assumes that all nations comply with the Montreal Protocol and the 1990 London Agreements.[23] Second, the model applies these growth rates to the release rates for the chemicals.[24] This calculation generates the total emissions estimate for each chemical from 1985 to 2165.[25]

Stratospheric Ozone Depletion Modeling and Global Warming

Using the total emissions estimates of ODSs, the atmospheric lifetimes of the chemicals, and conversion factors, the EPA calculates stratospheric chlorine and bromine concentrations. Lifetimes indicate the length of time that the chlorine and bromine associated with a specific chemical will likely remain in the atmosphere. Conversion factors relate the emissions to stratospheric ozone changes.[26] To translate changes in stratospheric chlorine and bromine concentrations to changes in total column ozone, the EPA modifies Connell's parameterized version of a one-dimensional atmospheric chemistry model.[27] The EPA calibrates this model to incorporate the effects of atmospheric processes (e.g., heterogeneous chemical reactions) by applying an adjustment factor to the stratospheric ozone content; this calibration ensures that the model's global results are consistent with historical ozone trends for northern hemisphere middle and high latitudes.[28] The EPA's model assumes that increases in stratospheric chlorine are the primary causes of the observed ozone change and that the annual average change in UV-b predicted by the modeling framework equals the annual average UV-b change inferred from observed ozone trends and radiation models.

In conjunction with the calibrated version of Connell's parameterized model, a second model incorporates the ability of CFCs, halons, MCF, carbon tetrachloride, and HCFCs to act as greenhouse gases (substances that contribute to the warming of the earth's atmosphere by absorbing infrared radiation emitted from the earth's surface).[29] This second model, adapted from the

the Stratospheric Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency, September 10, 1993, page 9.

[23] Ibid, ICF (1993a), 9; Ibid ICF (1992), 3-6 and 3-12.

[24] Ibid, ICF (1993a), 1; Ibid ICF (1992), 3-12.

[25] ICF Incorporated's *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs* (1993a) does not present emissions estimates.

[26] The sources of the ozone depleting potential estimates include Fisher *et al.* (1990a) and the 1987 Montreal Protocol. (ICF Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals*, Prepared for the Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, 1992, page 3-16.)

[27] Connell, Peter, "A Parameterized Numerical Fit to Total Column Ozone Changes Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere," Lawrence Livermore National Laboratory, Livermore, CA, 1986. (For a description of the stratospheric ozone model, see U.S. Environmental Protection Agency, *Assessing the Risks of Trace Gases that Can Modify the Stratosphere*, 1987; U.S. Environmental Protection Agency, *Future Concentrations of Stratospheric Chlorine and Bromine*, EPA 400/1-88-005, August 1988; and U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Protection of Stratospheric Ozone*, August 1, 1988.)

[28] Rodriguez, J.M., M.K.W. Ko, and N.D. Sze, " Antarctic Chlorine Chemistry: Possible Global Implications," *Geophysical Research Letters, 15*, 1988, pages 257-260.

[29] CFC substitutes may indirectly influence global warming by affecting the energy efficiency of CFC-using capital stock (e.g., insulating foam and refrigerators). As chemicals that are more or less energy efficient replace CFCs, total energy demand could diminish or increase, causing changes in the emissions of energy-related greenhouse gases. (ICF Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals*, Prepared for the Global

Goddard Institute of Space Sciences' climate model, uses estimates for emissions of controlled chemicals, substitute chemicals, and energy-related greenhouse gases to calculate changes in global temperature over time.[30] The model adjusts column ozone and temperature so that they are consistent with consensus ozone-depleting potential and global warming potential estimates.[31] The model also reflects 1) radiative and chemical feedback from water vapor, 2) ocean absorption, 3) atmospheric circulation effects, and 4) chemical interactions between substances.[32, 33]

Estimates from stratospheric ozone modeling may be under- or overestimates, depending on heterogeneous reactions in the aerosol layer, ozone depletion in the Arctic, the linearity of the atmospheric response, and other factors.[34] The EPA estimates that the accelerated reduction and phaseout schedules of section 604 and 606 will result in 7 percent less ozone depletion from baseline levels in 2005 and 47.01 percent less ozone depletion in 2075.[35]

Physical Effects

For the physical effects that scientists have modeled with dose-response functions, we use data on UV-b radiation and tropospheric ozone to calculate benefits. We include benefits that scientists have identified but not yet quantified in a qualitative discussion. Below we present the benefits methodology for each section.

Physical Effects: Sections 604 and 606

Table G-4 presents the quantified and unquantified physical effects estimates of sections 604 and 606, which generate about 98 percent of the benefits. The quantified benefits include the following: reduced incidences of mortality and morbidity associated with skin cancer (melanoma and nonmelanoma); reduced incidences of cataract morbidity and the associated pain and suffering; reduced crop damage associated with UV-b radiation and tropospheric ozone; and reduced polymer degradation from UV-b radiation.

Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, 1992, pages 3-17 and 3-18.)

[30] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Protection of Stratospheric Ozone*, August 1, 1988; ICF Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals*, Prepared for the Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, 1992, page 3-18.

[31] National Aeronautics and Space Administration Conference Publication 3023, *An Assessment Model for Atmospheric Composition*, 1988; ICF Incorporated, *Regulatory Impact Analysis: The National Recycling and Emission Reduction Program (Section 608 of the Clean Air Act Amendments of 1990)*, Prepared for the Stratospheric Protection Division, U.S. Environmental Protection Agency, 1993, page 5-2.

[32] Radiative forcing constants and lifetimes form the basis of the global warming potential estimates, calculated with an infinite time horizon (Lashof and Ahuja, 1990). Fisher *et al.* provide data on direct radiative forcing constants (Fisher *et al.*, 1990b).

[33] ICF Incorporated, *Regulatory Impact Analysis: The National Recycling and Emission Reduction Program (Section 608 of the Clean Air Act Amendments of 1990)*, Prepared for the Stratospheric Protection Division, U.S. Environmental Protection Agency, 1993, page 5-2; ICF, Incorporated, *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs*, Prepared for the Stratospheric Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency, September 10, 1993, page 9.

[34] ICF Incorporated, *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals*, Prepared for the Global Change Division, Office of Air and Radiation, U.S. Environmental Protection Agency, 1992, page 5-8.

[35] ICF, Incorporated, *Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs*, Prepared for the Stratospheric Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency, September 10, 1993, page 14.

Table G-4
Benefits of Section 604, 606, and 609

Health Effects- Quantified	**Estimate**	**Basis for Estimate**
• Melanoma and nonmelanoma skin cancer (fatal)	6.3 million lives saved from skin cancer in the U.S. between 1990 and 2165	Dose-response function based on UV exposure and demographics of exposed populations.[1]
• Melanoma and nonmelanoma skin cancer (non-fatal)	299 million avoided cases of non-fatal skin cancers in the U.S. between 1990 and 2165	Dose-response function based on UV exposure and demographics of exposed populations.[1]
• Cataracts	27.5 million avoided cases in the U.S. between 1990 and 2165	Dose-response function uses a multivariate logistic risk function based on demographic characteristics and medical history. [1]
Ecological Effects- Quantified	**Estimate**	**Basis for Estimate**
• American crop harvests	Avoided 7.5 percent decrease from UV-b radiation by 2075	Dose-response sources: Teramura and Murali (1986), Rowe and Adams (1987)
• American crops	Avoided decrease from tropospheric ozone	Estimate of increase in tropospheric ozone: Whitten and Gery (1986). Dose-response source: Rowe and Adams (1987)
• Polymers	Avoided damage to materials from UV-b radiation	Source of UV-b/stabilizer relationship: Horst (1986)
Health Effects- Unquantified		
Skin cancer: reduced pain and suffering		
Reduced morbidity effects of increased UV. For example, • reduced actinic keratosis (pre-cancerous lesions resulting from excessive sun exposure) • reduced immune system suppression.		
Ecological Effects- Unquantified		
Ecological effects of UV. For example, benefits relating to the following: • recreational fishing • forests • overall marine ecosystem • avoided sea level rise, including avoided beach erosion, loss of coastal wetlands, salinity of estuaries and aquifers • other crops • other plant species • fish harvests		
Ecological benefits of reduced tropospheric ozone relating to the overall marine ecosystem, forests, man-made materials, crops, other plant species, and fish harvests		
Benefits to people and the environment outside the U.S.		
Effects, both ecological and human health, associated with global warming.		

Notes:

1) For more detail see EPA's *Regulatory Impact Analysis: Protection of Stratospheric Ozone* (1988).
2) Note that the ecological effects, unlike the health effects, do not reflect the accelerated reduction and phaseout schedule of section 606.
3) Benefits due to the section 606 methyl bromide phaseout are not included in the benefits total because the EPA provides neither annual incidence estimates nor a monetary value. The EPA does provide, however, a total estimate of 2,800 avoided skin cancer fatalities in the U.S.

Using the change in UV radiation exposure due to current and future ozone depletion, we estimate the number of additional cases of skin cancer (melanoma and non-melanoma) and cataracts. With the exception of non-melanoma mortality, which is estimated as a fixed percentage of non-melanoma incidence, we use dose-response functions to develop future incremental skin cancer estimates. We employ nearly identical approaches in developing the three dose-response functions for non-fatal non-melanoma (i.e., basal cell and squamous cell carcinoma), non-fatal melanoma, and fatal melanoma.

The first step uses results from studies that have identified key groups of wavelengths ("action spectra") within the UV spectrum that are associated with specific types of health effects (e.g., DNA damage).[36] Once the appropriate action spectrum for a health effect is determined, the next step involves estimating the amount of UV dose received at various latitudes across the U.S. in the years prior to ozone depletion. The third step involves obtaining nationwide skin cancer incidence and mortality data for each health effect.[37] These data are then combined with the estimated variation in UV doses across latitudes in a cross-sectional analysis of the relationship between skin cancer incidence or mortality and differences in UV exposure.[38] This statistical analysis uses an equation of the form: (fractional change in incidence) = (fractional change in UV dose + 1)^b -1, where b (the biological amplification factor) equals the percent change in incidence associated with a one percent change in dose. The dose-response function for cataracts is developed similarly.[39]

The health benefits model uses these dose-response functions to project incremental cases of non-fatal non-melanoma, fatal and non-fatal melanoma, and cataracts that will occur due to future increases in UV exposure caused by stratospheric ozone depletion. In essence, future incremental health effects are estimated by multiplying the baseline level of each health effect by the percentage change in UV exposure for different latitudes in the U.S. times the appropriate dose-response factor. Because the baseline levels of all of these UV-related health effects tend to be higher for older people and for those with lighter skins, our method for projecting future incremental skin cancers and cataracts incorporates this and other relevant factors in its benefits estimates. Estimates of non-melanoma fatalities are not calculated from a dose-response function. Instead, the model assumes that the number of non-melanoma deaths will be a fixed percentage of the

[36] Setlow, R.B., "The Wavelengths of Sunlight Effective in Producing Skin Cancer: A Theoretical Analysis," Proceedings of the National Academy of Sciences, 71(9):3363-3366, 1974.

[37] Non-fatal basal and squamous cell non-melanoma incidence rates were obtained from Scotto, J., T. Fears, and Fraumeni, "Incidence of Nonmelanoma Skin cancer in the United States," U.S. Department of Health and Human Services, (NIH) 82-2433, Bethesda, MD, 1981. Non-fatal melanoma incidence rates were obtained from National Cancer Institute SEER Report, 1984. Fatal melanoma incidence rates were obtained from Pitcher, H.M., "Examination of the Empirical Relationship Between Melanoma Death Rates in the United States 1950-1979 and Satellite-Based Estimates of Exposure to Ultraviolet Radiation," U.S. EPA, Washington, DC, March 17, 1987, draft.

[38] Non-fatal Non-Melanoma: Scotto, J, and T. Fears, "Estimating Increases in Skin Cancer Morbidity Due to Increases in Ultraviolet Radiation Exposure," Cancer Investigation, 1(2), 119-126, 1983. Non-fatal Melanoma: Scotto, J, and T. Fears, "The Association of Solar Ultraviolet and Skin Melanoma Incidence Among Caucasians in the United States," Cancer Investigation, 5(4), 275-283, 1987. Melanoma mortality: Pitcher, H.M., and J.D. Longstreth, "Melanoma Mortality and Exposure to Ultraviolet Radiation: An Empirical Relationship, Environment International, vol. 17, 7-21, 1991.

[39] Cataract prevalence data were obtained from Leske and Sperduto, "The Epidemiology of Senile Cataracts: A Review," American Journal of Epidemiology, Vol. 118, No.2, 152-165, 1983. For information on the dose-response relationship, see Hiller, R., R. Sperduto, and F. Ederer, "Epidemiological Associations with Cataract in the 1971-1972 National Health and Nutrition Survey," American Journal of Epidemiology, Vol. 18, No. 2, 239-249, 1983.

total non-melanoma cases.[40] We estimate that from 1990 to 2165 sections 604 and 606 will result in 6.3 million avoided deaths from skin cancer, 27.5 million avoided cataract cases, and 299.0 million cases of non-fatal skin cancers (melanoma and non-melanoma).

Although the evidence linking UV-b and melanoma is controversial, studies suggest that exposure to sunlight is a major environmental risk factor for melanoma. However, uncertainty exists about three aspects of this relationship: the appropriate action spectrum (i.e., the relative contribution of different wavelengths of light to overall risk), the appropriate dose metric (acute, intermittent, or chronic), and the importance of age at exposure. Although UV-b was initially thought to be solely responsible for melanoma, studies by Setlow et al. (1993) and Ley (1997) have shown that UV-a as well as UV-b is a significant factor in the induction of melanoma. The uncertainty surrounding the dose-metric stems from the fact that chronic, cumulative, low-level exposures to sunlight are not associated with development of melanoma. Instead, melanoma risk is higher among those intermittently exposed to sunlight and that melanoma occurs most frequently on body parts that are intermittently exposed. Therefore, current thinking suggests that intermittent, intense bursts of UV exposure (i.e., sunburns) are an important factor in the development of melanoma. Epidemiological studies exploring this hypothesis have confirmed such an association, though the strength of these findings may be weakened by recall bias (Berwick 1998). Finally, melanoma may exhibit a significant latency period; studies such as Holman and Armstrong (1984) have found that severe early life exposures to UV are an important risk factor for melanoma in adults. However, the most recent study of this effect (Autier and Dore, 1998) found that childhood exposures are important only in addition to severe adult exposures.

[40] Non-melanoma mortality estimates are based on the assumption that one percent of non-melanoma incidence results in mortality.

The effect of the uncertainties in the first two aspects of the UV/melanoma relationship (action spectrum and dose metric) on the melanoma mortality estimates is difficult to determine based on current information. If melanoma mortality exhibits a latency period, our results may be overestimated, because the analysis did not specifically model a latency period.

To estimate crop damage, we apply earlier studies on the relationship between crops, UV-b radiation, and tropospheric ozone to the changes in UV-b radiation and tropospheric ozone predicted by the emissions models.[41] We estimate that the avoided increase in damage to American crop harvests from UV-b radiation by 2075 will equal about 7.5 percent. To calculate the benefits of avoided photodegradation of all UV-b sensitive polymers, we use the Horst *et al.* study (1986) on the relationship between UV-b radiation and the increase in polymer stabilizers needed to mitigate rigid PVC pipe damage.[42]

The unquantified effects of sections 604 and 606 include the following: avoided pain and suffering from skin cancer, ecological effects of UV-b radiation and tropospheric ozone, human health and environmental benefits outside the United States, and changes in pulmonary and respiratory

[41] Sources of dose-response relationship for crops and UV-b: Teramura and Murali (1986) and Rowe and Adams (1987). Source of dose-response relationship for crops and tropospheric ozone: Rowe and Adams (1987). Source of increased tropospheric ozone estimates: Whitten and Gery (1986). Our benefits analysis does not include assessing the effects of tropospheric ozone on forests. Although there are C-R functions available that would allow an assessment, we could not use them because of we do not have the necessary measure of tropospheric ozone changes.

[42] Although the *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals* provides monetized benefits estimates of reduced crop damage from tropospheric ozone and reduced polymer damage from UV-b, it does not provide a quantified estimate in non-monetary terms.

functions from increased tropospheric ozone.[43] The EPA also lists avoided actinic keratosis (pre-cancerous lesions from excessive sun exposure) as another unquantified benefit. Using the first National Health and Nutrition Examination (NHANES I), Engles *et al.* linked increased UV exposure to increased incidence of actinic keratosis.[44] This study, however, did not provide sufficient quantitative information relating the incidence of actinic keratosis to levels of UV radiation. In addition, several researchers provide data suggesting that avoided increases in infection intensity may constitute an unquantified benefit. For example, Perna *et al.* associated UV-b exposure with the reactivation of Herpes virus infections.[45] Other studies have linked UV exposures to reductions in the ability of animals to control infections with *Leishmania sp.* (Giannini and DeFabo); malaria (Taylor and Eagles). The yeast candida (Denkins *et al.* and Chung *et al*);.the bacterium *staphylococcus aureus* (Chung *et al*).[46] Valerie *et al.* also showed that UV irradiation of cells grown *in vitro* and exposed to sunlight for as little as 10 to 30 minutes can activate the human immunodeficiency virus type 1 (HIV-1).[47] Scientists, however, have not yet provided a quantitative relationship between the impact of UV-b-induced immunosuppression and human disease.[48]

Physical Effects: Sections 608, 609, and 611

For sections 608, 609, and 611 we base the quantified benefits estimates on the methodology used for sections 604 and 606, but do not provide the quantified estimates cited in the RIAs. For section 608 we use the same emissions, stratospheric ozone, and UV-b radiation methodologies used for sections 604 and 606; the quantified benefits of section 608, however, comprise only benefits from reduced incidences of skin cancer morbidity and mortality. For section 609 the benefits estimate is simply a percentage of the benefits of section 604; in fact, we avoid double counting by omitting 609 benefits from the calculation of the total Title VI benefits estimate. For section 611 we calculate the benefits estimate with a benefit per kilogram ratio obtained from data in the *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals* (1992). We apply this ratio to the emissions reduction caused by firms that accelerate the use of MCF substitutes to avoid labeling.

The unquantified benefits estimates of sections 608, 609, and 611 are the same as the unquantified benefits of sections 604 and 606, with one exception. The analysis of section 611 includes two additional benefits: an increase in available information regarding ozone-depleting substances and enhanced implementation and enforcement of EPA's refrigerant recycling program. Quantified

[43] ICF Incorporated's *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone-Depleting Chemicals* (1992) does not present the information on the studies linking tropospheric ozone with pulmonary and respiratory effects.

[44] Engles, A., M.L. Johnson, and S. Haynes,"Health Effects of Sunlight Exposure in the United States: Results from the First National Health and Nutrition Examination Survey, 1971-1974," *Archives of Dermatology*, Vol. 4, January 1988, pages 72-79.

[45] Perna, J.J., M.L. Mannix, J.E. Rooney, A.L. Notkins, and S.E. Straus, "Reactivation of Latent Herpes Simplex Virus Infections by Ultraviolet Light: A Human Model," *Journal of the American Academy of Dermatology*, 17, 1987, pages 473-478.

[46] Chung, H.T., D.C. Lee, S.Y. Im, and R.A. Daynes, "UVR-Exposed Animals Exhibit and Enhanced Susceptibility to Bacterial and Fungal Infections," *Journal of Investigative Dermatology,* Vol. 90, No. 4, April 1988, page 52; Denkins, Y., I.J., Fidler, and Kripke, M.L., "Exposure of Mice to UV-B Radiation Suppresses Delayed Hypersensitivity to *Candida albicans*," *Photobiology and Photochemistry*, 1989; Giannini, S.H., and E.C. DeFabo, "Abrogation of Skin Lesions in Cutaneous Leishmaniasis by Ultraviolet B Irradiation," *Leishmaniasis: The First Centenary (1885-1985) New Strategies for Control*, Heart, D.T. (ed.), NATO ASI Series A: Life Sciences , London, Plenum Pub., Cos.; Taylor, D.W. and D.A. Eagles, "Assessing the Effects of Ultraviolet Radiation on Malarial Immunity," Prepared for Sabotka and Company under EPA contract number 68-01-7288, subcontract number 132.914.

[47] Valerie, K., A. Delers, C. Bruck, C. Thiriart, H. Rosenberg, C. Debouck, and M. Rosenberg, "Activation of Human Immunodeficiency Virus Type 1 by DNA Damage in Human Cells," *Nature,* Vol. 333, May 5, 1988, pages 78-81.

[48] Ibid, ICF (1992), 6-26.

and unquantified benefits of 608 and 611 are summarized in Table G-5 and G-6 respectively.

Table G-5
Benefits of Section 608

Quantified Health Effects
Skin cancer: fatal and nonfatal
Health Effects- Unquantified
Skin cancer: reduced pain and suffering
Cataracts: reduced morbidity, pain and suffering
Reduced morbidity effects of increased UV. For example, • reduced actinic keratosis (pre-cancerous lesions resulting from excessive sun exposure) • reduced immune system suppression.
Ecological Effects- Unquantified
Ecological effects of UV. For example, benefits relating to the following: • recreational fishing • forests • overall marine ecosystem • avoided sea level rise - which, in turn, leads to: decreased beach erosion decreased loss of coastal wetlands decreases in the salinity of estuaries and aquifers • other crops • other plant species
Other ecological benefits of reduced tropospheric ozone relating to • the overall marine ecosystem • forests • man-made materials (e.g., degradation of elastomers, textile fibers and dyes, certain paints) • other crops • other plant species
Benefits to people and the environment outside the U.S.
Effects, both ecological and human health, associated with global warming.

Table G-6
Benefits of Section 611

Health Effects- Quantified
Skin cancer: fatal and nonfatal
Cataracts: reduced morbidity, pain and suffering
Ecological Effects- Quantified
Crops: reduced damage associated with increased UV radiation
Crops: reduced damage associated with increased tropospheric ozone
Polymers: reduced degradation from UV-b radiation
Health Effects- Unquantified
Skin cancer: reduced pain and suffering
Reduced morbidity effects of increased UV. For example, • reduced actinic keratosis (pre-cancerous lesions resulting from excessive sun exposure) • reduced immune system suppression
Ecological Effects- Unquantified
Ecological effects of UV. For example, benefits relating to the following: • recreational fishing • forests • overall marine ecosystem • avoided sea level rise - which, in turn, leads to: decreased beach erosion decreased loss of coastal wetlands decreases in the salinity of estuaries and aquifers • crops in general • other plant species • fish harvests
Ecological benefits of reduced tropospheric ozone relating to • the overall marine ecosystem • forests • man-made materials (e.g., degradation of elastomers, textile fibers and dyes, certain paints) • crops in general • other plant species • fish harvests
Benefits to people and the environment outside the U.S.
Enhanced implementation and enforcement of EPA's refrigerant recycling program
Increase in available information regarding ozone-depleting substances (ODSs); consumers who wish to buy products that do not contain ODSs will be better able to express their preferences through their purchasing power.
Effects, both ecological and human health, associated with global warming.

Valuation

To calculate monetary values of the quantified benefits, we multiply the physical effects estimates by the appropriate physical effects value. For the health benefits, we use $15,000 for the avoided cost of cataracts, $15,000 for the avoided cost of melanoma skin cancer, and $5,000 for the avoided cost of nonmelanoma skin cancer.[49] This analysis employs a value of statistical life of $4.8 million (1990 dollars), which is the value used to calculate the criteria pollutant mortality benefits estimate presented in Chapter 6, Table 6-3. To calculate the monetary benefits of increased crop yields, the model multiplies the change in crop yields by crop values from the Department of Agriculture.[50] To calculate the monetary benefits related to fish, we apply $739 per ton (1990 dollars) to the increase in fish harvests.[51] We define the polymer benefits as the avoided loss in consumer surplus associated with increased polymer prices. We assume that the cost is proportional to the increase in price following the addition of stabilizers and that the price of polymer stabilizers will increase by 1.86 percent for each 25 percent increase in stabilizer.[52]

With a two percent discount rate, the benefits of sections 608, 609, and 611 are $671 million, $296 million, and $831 million (1990 dollars), respectively. We do not separate these values into their components. The total monetized health benefits for section 604 and 606 with a two percent discount rate are $4.2 trillion and the total monetized ecological benefits are $92.5 billion; thus, the total benefits of sections 604 and 606 are about $4.3 trillion. Table G-7 is a tabular summary of the monetary values of the benefits from sections 604 and 606, which generate about 98 percent of the monetized benefits.[53]

[49] Wasson, John and Steve Abseck, "Memorandum: Further Detail on the Costs and Benefits of Phasing Out Ozone Depleting Substances, EPA Contract No. 68-D4-0103, WA-205," Prepared for Jim DeMocker, U.S. Environmental Protection Agency, October 9, 1995.

[50] The RIAs do not provide the specific crop values used.

[51] The U.S. Department of Commerce provides the fish values. (Ibid, ICF (1992), 6-29.)

[52] Ibid, ICF (1992), 6-41.

[53] The dollar year was not available for some cost of illness estimates in Table G-7. Because these estimates come from a 1988 RIA, we are thus underestimating the monetized benefits of the health effects associated with these unadjusted values.

Table G-7
Sections 604 and 606: Valuation of Total Benefits from 1990 to 2165, With a Two Percent Discount Rate

Quantified Effects	Valuation (1990 dollars)	Source Data
Health Effects		
Mortalities from skin cancer (melanoma and nonmelanoma) in the U.S. (1990-2165)	$3,900 billion	Value of statistical life: $4.8 million (1990 dollars). (See Appendix H for a description of source data.)
Cataract cases in the U.S. (1990-2165)	$72 billion	Avoided cost of cataracts: $15,000 (dollar year not provided) Costs include increased medical costs, increased work loss, increased costs for chores, other indirect social and economic costs, and willingness to pay to avoid cataracts. Data from literature review, contacts with health providers, and cataract patient survey. (Source: Rowe *et al.* 1987)
Nonfatal skin cancer cases (melanoma and nonmelanoma) in the U.S. (1990-2165)	$220 billion	Cost of melanoma skin cancer: $15,000 per case (dollar year not provided); costs of nonmelanoma skin cancer: $5,000 per case (dollar year not provided). Estimates include increased medical costs and decreased productivity but do not include costs of caregiving and chores performed by others. Data from Skin Cancer Focus Group. (See ICF's August 1988 RIA for details.)
Total Health Benefits	**$4,200 billion**	
Ecological Effects		
• Decrease in American crop harvests from UV-b radiation by 2075	$49 billion	Crop values from Department of Agriculture.
• Decrease in American crops from tropospheric ozone by 2075	$28 billion	Crop values from Department of Agriculture.
• Damage to polymers from UV-b radiation by 2075	$6 billion	Costs are proportional to the increase in polymer prices following the addition of stabilizers. Price increase of 1.86% expected for a 25% increase in stabilizer.
Total Environmental Benefits	**$84 billion**	
Total Benefits	**$4,300 billion**	

Note : 1) The RIAs do not provide specific crop values

Adjustments to Estimates From Existing Analyses

To ensure consistency with assumptions in other portions of the current study, we adjust certain parameters used in existing regulatory impact assessments of Title VI provisions. We vary several parameters and compare the resulting net present values of Title VI's costs and benefits. The Title VI analysis generates net present values, rather than annualized values, because annualization incorrectly imputes benefits of later phaseouts to earlier years. For example, annualization of the benefits of phasing out HCFC-22 by 2020 attributes benefits to years prior to 2030, when neither the costs nor the benefits of that phaseout have yet occurred. Consequently, the annualized estimate overstates benefits at the beginning of the time span and understates them later.

Table G-8 describes the values we use for the following parameters: discount rate and value of statistical life. We are able to adjust key parameters in the benefits analyses of sections 604, 606, and 609 and the cost analyses of sections 604 and 606. We cannot adjust parameters for other sections, however, because we lack annual cost and benefit data from these sections.[54] Moreover, for section 604 and the accelerated phaseout schedule of section 606, we are unable to modify the parameters for the analysis of ecological benefits. Nevertheless, the benefits from sections 604 and 606 constitute the majority of Title VI benefits (approximately 98 percent at a two percent discount rate) and only about one percent of the benefits of these sections result from ecological benefits. In addition, sections 604 and 606 account for about 97 percent of the costs (at a two percent discount rate).

Discount Rate

Because the benefits occur over several hundred years, the chosen discount rate can have an especially large effect on the benefits estimate. In this analysis we use a five percent discount rate for our primary estimate. This is consistent with the retrospective analysis of the Clean Air Act and the other analyses conducted for the present study.[55] We also preform sensitivity tests using discount rates of three percent and seven percent. Finally, for consistency with cost and benefit estimates that we cannot adjust, we calculate aggregate benefits and costs using a discount rate of two percent.

[54] We calculate the benefits of section 609 as a percentage of the benefits of section 604, so we do not need annual data for section 609.

[55] U.S. Environmental Protection Agency, *The Benefits and Costs of the Clean Air Act, 1970 to 1990,* October 1997.

Table G-8
Adjustments to Key Parameters of Existing Analyses That Support the 812 Title VI Estimates

Parameter	Assumption for Section 812 Prospective	Adjustments to Title VI Analyses			
		Sections 604 and 606	Section 608	Section 609	Section 611
Discount Rate (Used for Costs and Benefits)	Central Case: 5% Sensitivity tests: 3% and 7%	Used Section 812 parameters, plus 2%.	2% (No adjustment possible.)	2% (No adjustment possible for costs.)	2% (No adjustment possible.)
Value of Statistical Life (Benefits Only)	Distribution of values from $0.6 million to $13.5 million with expected value of $4.8 million	Used Section 812 parameters.	$3 to $12 million	Used Section 812 parameters.	$3 to $12 million

Value of Statistical Life

The value of statistical life (VSL) is essential for measuring the monetized benefits associated with a reduced number of skin cancer mortality cases. We use a $4.8 million central estimate of VSL, based on analysis described in Appendix H. To reflect the uncertainty of the VSL estimates, we employ a Monte Carlo approach using a Weibull distribution of VSL estimates as an input. This distribution is the same as that used in the analysis of criteria pollutants.[56]

[56] The Weibull distribution has the following parameters: a location of $0.0, a scale of $5.32 million, and a shape of 1.509588.

Cost and Benefit Results With Adjusted Parameters

Both cost and benefit estimates are sensitive to the discount rate. As mentioned earlier, the discount rate has a particularly significant effect on the benefits estimate because the benefits occur over several hundred years (1990 to 2165). These benefits result from actions taken to reduce ozone-depleting chemical emissions from 1990 to 2075, the time period over which costa are incurred. In this section we first present the net present value of the costs and benefits using the central discount rate of five percent. We then discuss the results of the sensitivity tests using discount rates of three and seven percent. Lastly, we show the results using a two percent discount rate, which is consistent with the discount rates used in existing RIAs and which allows us to compare the costs and benefits of all the major sections of Title VI, including provisions where discount rate adjustments are not possible.

The adjusted primary benefit estimate (using a five percent discount rate) for Title VI is $530 billion and the cost estimate is $30 billion. The benefits range from $240 billion with a seven percent discount rate and $1,900 billion with a three percent discount rate. The costs range from $20 billion to $40 billion, with the same respective discount rates. The benefits of Title VI greatly exceed the costs for all discount rate assumptions; in fact, the benefits are about 20 times greater than the costs at a five percent discount rate.[57] (See Table G-9) Even the seven percent discount rate sensitivity test yields total benefits that are 12 times greater than the costs.

Five Percent Discount Rate

With a five percent discount rate, the expected human health benefits from sections 604 and 606 are approximately $400 billion. Table G-10 shows the results of the statistical simulation modeling analysis; the 5th and 95th percentile values are $100 billion to $900 billion, respectively. The annual human health benefits from sections 604 and 606, calculated with a five percent discount rate, steadily increase until about 2045; they then decrease until 2165, the last year in the analysis. (See Figure G-2.) About 93 percent of the benefits occur from 2015 to 2165.

The costs of sections 604 and 606 of Title VI are approximately $26 billion; these sections generate approximately 97 percent of the costs. The human health benefits for sections 604 and 606 are almost 17 times greater than the costs of these sections.

[57] Note that we do not include the costs of the methyl bromide phaseout of section 606 because existing RIAs do not provide benefits estimates for this phaseout. The costs, calculated with a three percent discount rate, are about $1.7 billion.

Table G-9
Costs and Benefits of Sections 604 and 606[1]

Discount Rate	Benefits (Trillions) 1990 Dollars	Costs (Trillions) 1990 Dollars	Benefits/Cost Ratio
2%	$4.24	$0.06	76
3%	$1.81	$0.04	44
5%	$0.44	$0.03	17
7%	$0.14	$0.02	8

Notes:

1. The cost and benefits estimates associated with a two percent discount rate are the estimates for sections 604, 606, 608, 609, and 611. For the other discount rates the estimates represent the costs and the human health benefits for sections 604 and 606. These two sections generate the majority of the Title VI costs and benefits (approximately 98 percent of the benefits and 97 percent of the costs in the two percent discount rate calculations).
2. We do not include the costs of the methyl bromide phaseout of section 606 because existing RIAs do not provide benefit estimates for this phaseout.
3. In general, the costs occur from 1990 to 2075, while the benefits occur from 1990 to 2165. (Tables G-11 and G-12 provide the specific time frame for each section of Title VI.)

Three Percent and Seven Percent Sensitivity Tests

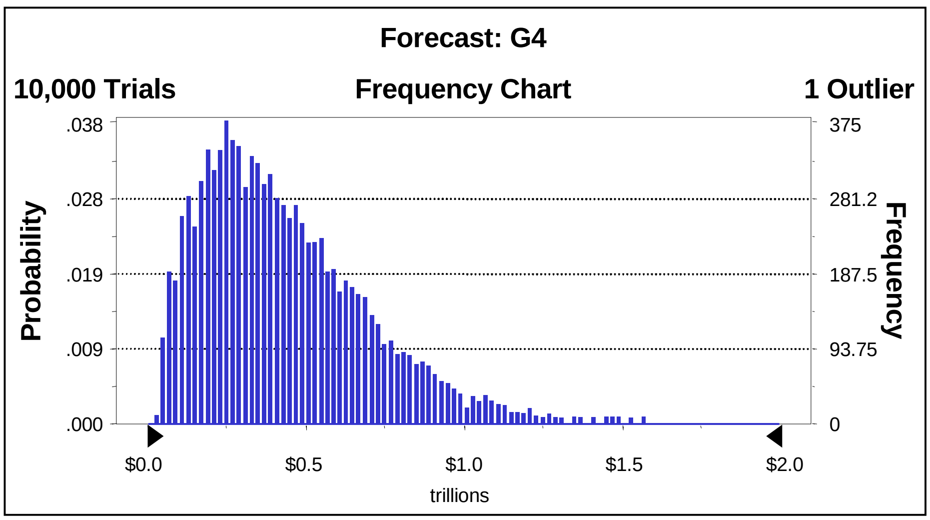
The expected human health benefits from sections 604 and 606 are approximately $1,800 billion at a three percent discount rate and $100 billion at a seven percent discount rate. With a three percent discount rate, the range of expected human health benefits is $100 billion to $7,800 billion, with 90 percent of these expected benefits between $400 billion and $4,000 billion. By contrast, at a seven percent discount rate the range of expected human health benefits is $14 billion to $700 billion, with 90 percent of the expected human health benefits between $33 billion and $300 billion.

The annual benefits from sections 604 and 606, calculated with a three percent discount rate, steadily increase until about 2062; they then decrease till 2165, the last year in the analysis. About 99 percent of the benefits occur from 2015 to 2165. At a seven percent discount rate the annual benefits from sections 604 and 606 steadily increase until about 2038 and then decrease till 2165. About 92 percent of the benefits calculated with a seven percent discount rate occur from 2015 to 2165.

The costs of sections 604 and 606 of Title VI are approximately $41 billion at a three percent discount rate and approximately $18 billion at a seven percent discount rate; these sections account for approximately 97 percent of the total costs. The costs for sections 604 and 606 are about 44 times smaller than the human health benefits for these sections at a three percent discount rate and about 8 times smaller at a seven percent discount rate.

Table G-10
Human Health Benefits for Sections 604 and 606

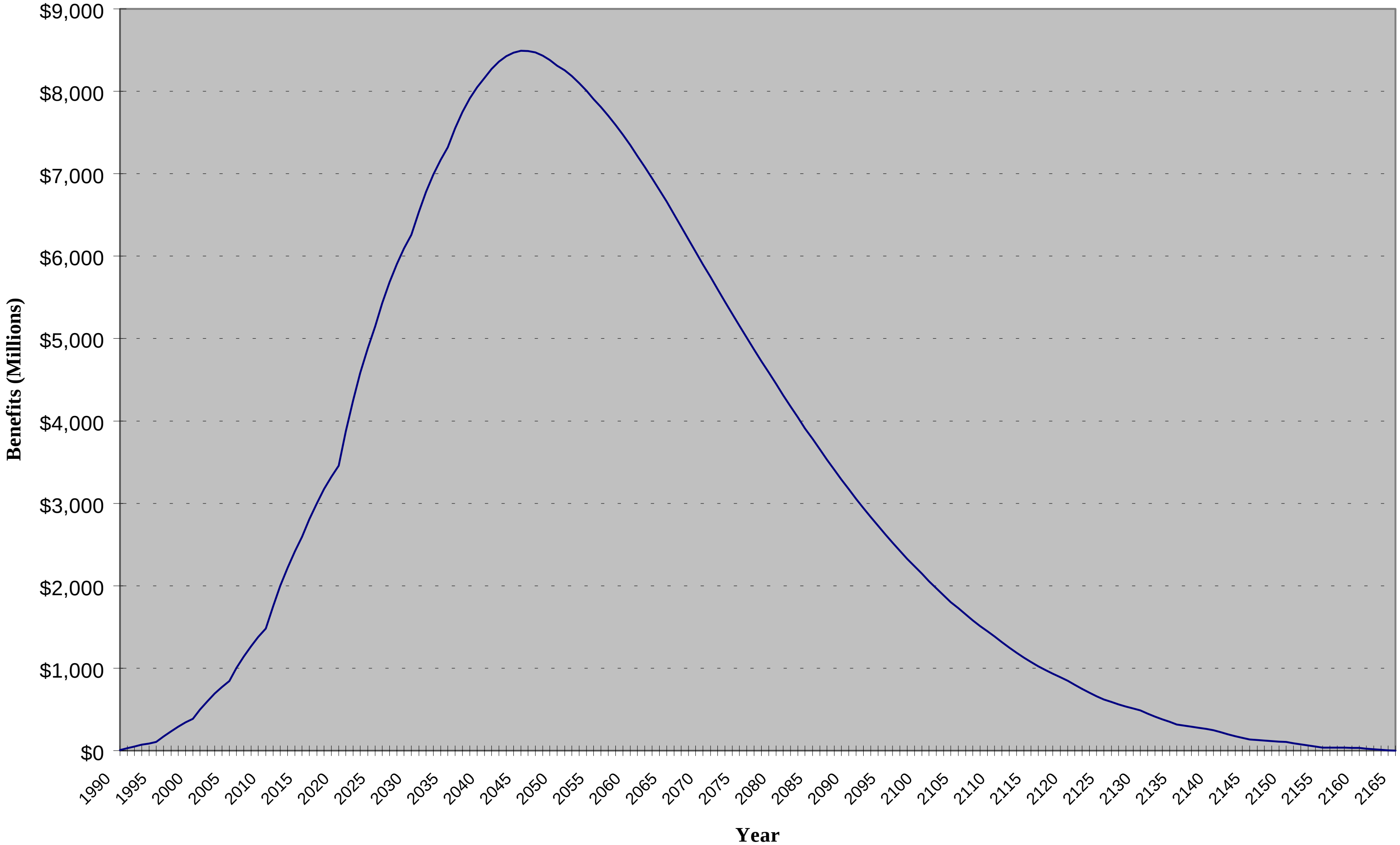
	Billions of 1990 dollars
Range:	$40 to $2,600
Mean:	$400
Median:	$400
Standard Deviation:	$300
Percentiles:	
5%	$100
50%	$400
95%	$900



Percent of Benefits from 1990 to 2014	3.64%
Percent of Benefits from 2015 to 2165	93.36%

Note: Estimates calculated with a five percent discount rate.

Figure G-2
Annual Human Health Benefits From Sections 604 and 606 (Discounted at 5%)



Two Percent Discount Rate

Using benefits estimates from RIAs for sections 608 and 611 and re-calculating the benefits of sections 604, 606, and 609 with a two percent discount rate and a VSL of $4.8 million yields a *total* benefits estimate of $4.3 trillion (1990 dollars) for Title VI.[58] (See Table G-11). Of this estimate, $4.2 trillion (98 percent) results from the human health benefits of sections 604 and 606. The range of expected benefits from human health improvements is $0.3 trillion to $20.8 trillion, with 90 percent of the expected benefits between $0.9 trillion and $9.4 trillion. The annual human health benefits from sections 604 and 606, calculated with a two percent discount rate, steadily increase from 1990 until about 2077; they then decrease till 2165. About 99 percent of the benefits occur from 2015 to 2165.

To estimate the costs of Title VI with a two percent discount rate, we use the estimates from the RIAs that analyze sections 608, 609, and 611 and we re-calculate the costs of sections 604 and 606 using the two percent discount rate.[59] Total present value Title VI costs with a two percent discount rate are approximately $57 billion. The cost estimate is about 76 times smaller than the comparable benefits estimate. Table G-12 lists the cost components.

[58] The RIAs for sections 608 and 611 present a lower bound benefits estimate that incorporates a $3 million VSL and an upper bound benefits estimate that incorporates a $12 million VSL. To obtain a point estimate, we weight the lower bound by 80 percent and the upper bound by 20 percent. (The benefits of section 608 do not include the HCFC phaseout benefits because the phaseout is too complex to model.) In addition, note that the benefits of section 609 are a subset of the benefits of sections 604 and 606, so we do not add them separately to the benefits of the other sections to obtain the total benefits.

[59] The estimate for section 611 is an average of the lower bound, which assumes that only companies using ODSs as solvents will label products, and an upper bound, which assumes that 10 times as many companies use solvent-cleaned products and will need to label their products. Also, the costs for section 608 do not include the costs of the HCFC phaseout.

Undiscounted Benefits

The annual undiscounted benefits from sections 604 and 606 steadily increase until about 2110; they then decrease in steps until 2165. The steps appear to be related to the application of 10-year cohort survival rates for persons born after 2075. See Figure G-3 for a graphical depiction of the annual benefits.

Table G-11

Summary of Benefits of Title VI with a Two Percent Discount Rate and $4.8 Million VSL

	Section	Benefits (Millions) 1990 Dollars	Notes	Years During Which Benefits Accrue
604 & 606	**Class I Phaseout**	**$4,338,000**		
	- Reduced Mortality, Cataracts, and Non-Fatal Cancers	$4,243,000		1990 to 2165
	- Methyl Bromide Reductions		No information currently available.	1994 to 2160
	- Ecological Benefits	$84,000		1989 to 2075
605	**Class II Phaseout**		No information currently available.	
608	**National Recycling and Emission Reduction Program**	**$670**	1) Only health effects are monetized. 2) The RIA for section 608 does not include benefits of HCFC phaseout because this phaseout is too complex and predicting baseline innovation is too difficult. 3) The benefits estimate listed is the weighted average of the benefits calculated with $3 million and $12 million for the VSL. (The $3 million estimate has a weight of 0.8 and the $12 million estimate has a weight of 0.2) 4) Benefits reflect the accelerated phaseout schedule.	1994 to 2165
609	**Servicing of Motor Vehicle Air Conditioners**	**$300**	The benefits of section 609 are a subset of the benefits of sections 604 and 606; we calculate section 609 benefits as 0.00682% of the benefits of 604 and 606 combined. (This percentage is the total benefits of 609 in 1989 dollars divided by the total 604 benefits in 1989 dollars.)	1991 to 2075
611	**Labeling**	**$830**	1) The benefits do not reflect the accelerated phase-out schedule. 2) The benefits estimate listed is the weighted average of the benefits calculated with $3 million and $12 million for the value of a statistical life. (The $3 million estimate has a weight of 0.8 and the $12 estimate has a weight of 0.2)	1989 to 2075
	TOTAL	**$4,339,000**		

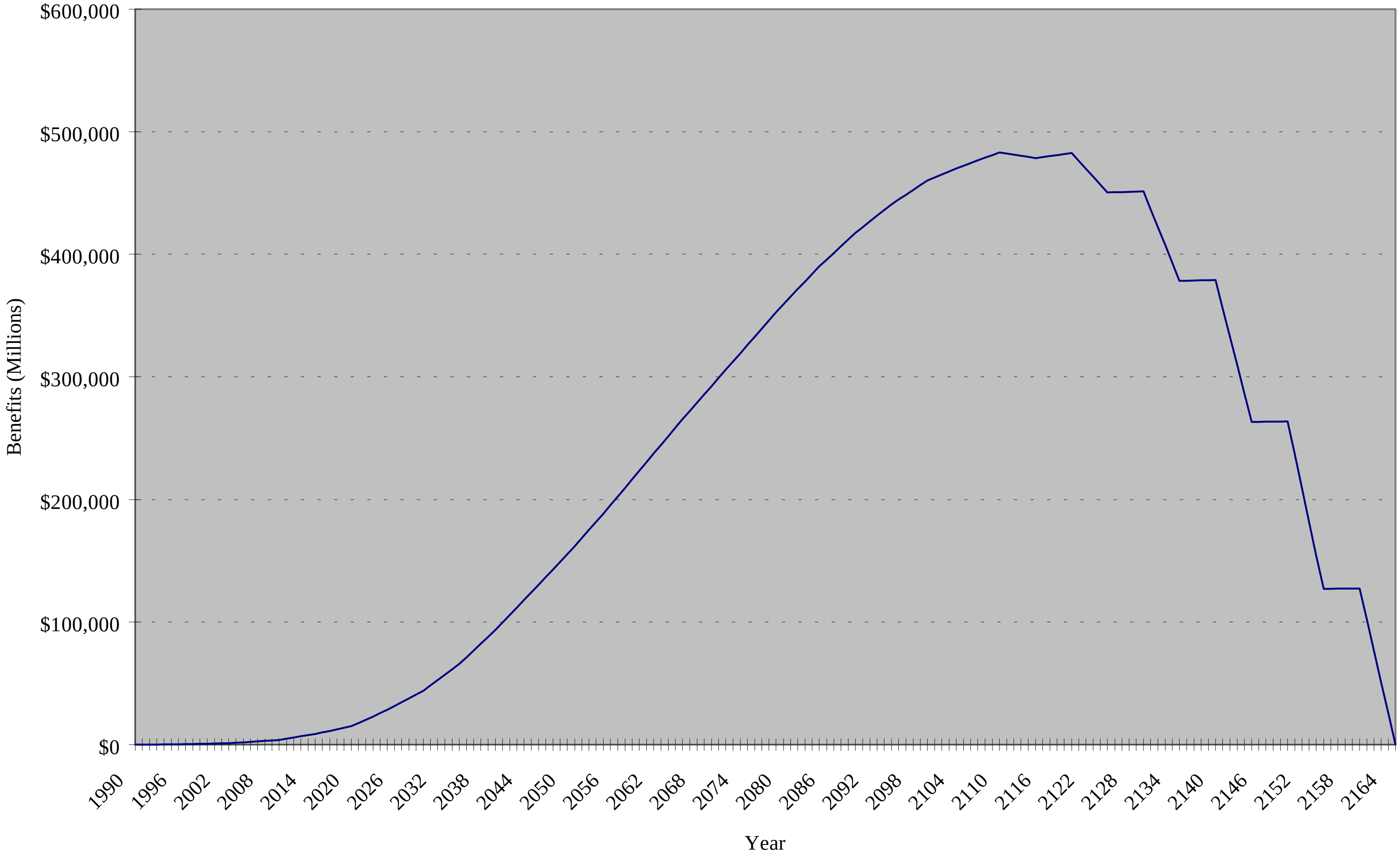
Notes: 1) All benefits expressed in 1990 dollars using the implicit GDP deflator from the *1998 Economic Report of the President.*
2) The benefits of section 611 and the ecological benefits of section 604 do not reflect the accelerated reduction and phaseout schedule of section 606.

Table G-12
Summary of Costs for Title VI by Section with a Two Percent Discount Rate

	Section	Cost Estimate (Millions, 1990 Dollars)	Notes	Years During Which Costs Accrue
604 & 606	**Class I Phaseout**	**$56,000**	Does not include cost of methyl bromide reductions.	1990 to 2075
605	**Class II Phaseout**		No information currently available.	
608	**National Recycling and Emission Reduction Program**	**$1,200**	1) We convert costs from 1991 to 1990 dollars using the GDP deflator from the *1998 Economic Report of the President*. 2) The RIA for Sect. 608 does not include costs of HCFC phaseout. 3) At a 4% discount rate the costs are $1,074.38 million, and at a 7% discount rate the costs are $853.91.	1994 to 2015
609	**Servicing of Motor Vehicle Air Conditioners**	**$14**	1) We convert from 1991 to 1990 dollars using the GDP deflator from the *1998 Economic Report of the President*. 2) To avoid counting the same costs for both section 604 and 609, we include only the operator training and equipment certification costs of section 609 here.	1992 to 2008
611	**Labeling**	**$250**	1) The costs are probably in 1990 dollars, but this is unclear. 2) Most costs are one-time costs. 3) The cost estimate is an average of the lower bound, which assumes that only firms using ODSs as solvents will label products, and an upper bound, which assumes that 10 times as many firms will need to label their products because they incorporate solvent-cleaned products.	1994 to 2000
	TOTAL	**$57,000**		

Notes:
1) The costs listed above for sections 604 & 606 do not include methyl bromide costs, which equal $1.7 billion with a 3% discount rate, because the RIA did not present the corresponding benefits.
2) The costs of sections 609 and 611 do not reflect the accelerated reduction and phaseout schedules of section 606.

Figure G-3
ANNUAL UNDISCOUNTED HUMAN HEALTH BENEFITS OF SECTIONS 604 AND 606



Limitations And Uncertainties

An analysis of programs that protect stratospheric ozone necessarily considers impacts over hundreds of years, introducing a wide range of uncertainty in the estimates of costs and benefits. There are clearly limitations and uncertainties in predicting the advancement of both medical treatment and ODS substitution technologies over time, modeling averting behavior of individuals in response to changes in UV-b radiation levels, anticipating the results of new information that might alter the modeling of stratospheric ozone depletion and formation, and forecasting economic parameters such as the growth in GDP and the valuation of health risk reduction.

We have not attempted to characterize the impact of all the uncertainties and limitations inherent in this type of analysis. For more detail, we refer the reader to the source material in EPA's RIAs for Title VI provisions and the descriptions of the cost and benefit modeling approaches found there. As part of this analysis, however, we conduct selected quantitative sensitivity tests and literature reviews to characterize several major uncertainties in the cost and benefits analyses presented here. The discussion that follows includes characterization of the following: issues in long-term discounting; limitations in the cost modeling; and limitations in the benefits modeling, including the modeling of averting behavior.

Long-term Discounting

As demonstrated above, the discount rate can have an important effect on the estimation of costs and benefits that accrue over a long period of time. Long-term discounting may present special problems that are worth exploring in some detail through sensitivity tests of alternative discount rate assumptions. For example, some economic literature suggests that accounting for intergenerational transfers in a manner different from intragenerational transfers may be appropriate.[60] One possible rationale for treating long-term, intergenerational transfers differently is that an individual's rate of time preference (which presumably applies only for his or her lifetime, or intragenerationally) may differ from his or her bequest motive for future generations. At least one empirical study suggests that individuals may implicitly apply lower discount rates for programs where the benefits accrue later in time.[61] In addition, people may attribute the same level of importance to all events that occur in the *far-distant* future, regardless of the relative position of these events in time. According to Weitzman, analysts should apply the lowest possible nonnegative rate to events in the far-distant future.[62]

Although some of the arguments for using an alternative discounting procedure for long-term benefits and costs are persuasive, implementation of an alternative procedure is not straightforward. There appears to be little guidance in the existing economic literature on the key issues of what discount rate to use for long-term versus short-term discounting as well as when to alter the discount rate. Recently drafted EPA guidance on the conduct of economic analyses, however, suggests that longer-term discount rates might be

[60] Arrow, K.J., W.R. Cline, K.G. Maler, M. Munasinghe, R. Squitieri, and J.E. Stiglitz, "Intertemporal Equity, Discounting, and Economic Efficiency," *Climate Change 1995: Economic and Social Dimensions of Climate Change*. Edited by J.P. Bruce, H. Lee, and E.F. Haites, Cambridge: Cambridge University Press, 1996; Lind, Robert C., "Intergenerational Equity, Discounting, and the Role of Cost-Benefit Analysis in Evaluating Global Climate Policy," *Integrative Assessment of Mitigation, Impacts, and Adaptation to Climate,* Edited by N. Nakicenovic, *et al.,* Laxenburg, Austria: International Institute of Applied Systems Analysis, 1994; Schelling, Thomas C., "Intergenerational Discounting," *Energy Policy*. 23(4/5), 1995, pages 395-401; Solow, Robert, "An Almost Practical Step Toward Sustainability," Paper presented at the Fortieth Anniversary of Resources for the Future, October 8, 1992, in Washington, D.C.

[61] Cropper, Maureen L., Sema K. Aydede, and Paul R. Portney, "Discounting Human Lives." *American Journal of Agricultural Economics*, December 1991: 1410-1414.

[62] Weitzman, Martin L., "Why the Far-Distant Future Should Be Discounted at its Lowest Possible Rate," *Journal of Environmental Economics and Management*, Volume 36, 201-208 (1998).

approximated through Ramsey Rule discounting, using effective annual discount rates of from 0.5 to 3.0 percent.[63] Throughout our presentation of Title VI cost and benefit results, we use a five percent discount rate for our primary estimate. We also calculate alternative estimates using three and seven percent discount rates. These discount rates maintain consistency with other analyses of the prospective.

Costs

Major uncertainties in the cost estimates result where it is difficult to predict the pace and nature of innovation in key industries. To the extent the models used do not quantify transition costs in the long term, the uncertainty in the cost estimates increases. In addition, predicting the responses of manufacturers to the different sections of Title VI is difficult. Table G-13 lists the primary causes of uncertainty in the cost estimates.

[63] We use the discount rate of 0.5 percent as a low nonnegative discount rate for events in the far-distant future. (Frank Arnold *et al.*'s *Draft Final Report: Discounting in Environmental Policy Evaluation* supports long-term discount rates from 0.5 percent to 3.0 percent.)

Table G-13
Major Limitations of Existing Cost Analyses for Title VI

Limitations	Effects on Cost Estimates
Sections 604*, 606, and 609	
The assumption of little or no technical innovation in ODS-related industries over the time span of the analysis may be inaccurate.	Inclusion of innovation may decrease the cost estimate.
The model does not quantify transition costs, such as temporary layoffs, administrative costs, and the costs of unknown environmental hazards created by the use of alternatives to CFCs.	Inclusion of transition costs may increase the cost estimate.
Section 608	
The assumptions of the capital and operating costs of recovery devices and the time necessary to perform recycling operations are largely hypothetical.	A better understanding of the capital and operating costs, as well as the time necessary for recycling, may either increase or decrease cost estimates.
The extent of compliance with recycling rates mandated by the Venting Prohibition is very uncertain.[1] Therefore, the baseline assumptions regarding the percentages of CFCs that are actually recycled are also very uncertain.	A better ability to forecast recycling rates may either decrease or increase cost estimates.
The baseline recycling value assumes no innovation in recycling technologies through 2017, which may be inaccurate.	Including innovation in recycling technologies may decrease the cost estimates.
Section 611	
Manufacturers' responses to the labeling requirement may include labeling, reformulating products, ceasing production, or petitioning for an exemption to the labeling requirement. Predicting the frequency of these responses is difficult.	A better ability to forecast manufacturers' responses may either decrease or increase cost estimates.

Note: *We do not include the costs of the methyl bromide phaseout in the total cost estimate because the RIAs do not provide the benefits of this phaseout. The cost estimates for the methyl bromide phaseout are uncertain, because the model assumes that the demand for output manufactured with methyl bromide is perfectly inelastic and that the methyl bromide production industry is perfectly competitive. While these assumptions may be unrealistic, they allowed the analysis to focus on consumer impacts and ignore effects on output markets.

[1] The Venting Prohibition is essentially a recovery and recycling requirement. For more detail see ICF (1993).

Benefits

Several factors contribute to uncertainty in the benefit estimates. (See Table G-14 for a list of major limitations.) For example, scientists have an incomplete understanding of the processes that govern ozone depletion and affect exposure to UV-b radiation. In addition, the dose-response coefficients relating UV-b exposure to melanoma skin cancer and cataracts are difficult to estimate. Scientists have not yet developed quantified dose-response relationships for some benefits, such as reduced damage to the immune system from UV-b radiation. As a result, the benefit estimates may either overestimate or underestimate the true benefits of Title VI provisions.

Data limitations also impede attempts to monetize certain benefits. For example, there are well established concentration-response functions that would allow us to measure the effects of tropospheric ozone on forests. We are, however, unable to use the CR functions because we do not have the necessary measured changes in ozone. As a result, we are also unable to monetize these benefits.

Another difficulty involves the long term nature of the study. Predicting invention, research and development, producer and consumer responses to price changes, and technological change for the next century and a half is highly speculative. Predicting major natural events that influence the effects of stratospheric ozone depletion is also difficult.[64] Our inability to forecast with accuracy may cause the benefit estimate to be too high or too low.

Lastly, the quantitative analysis of Title VI does not account for potential increases in averting behavior (e.g., people's efforts to protect themselves from UV-b radiation). Murdoch and Thayer (1990) estimate that the cost-of-illness estimates for nonmelanoma skin cancer cases between 2000 and 2050 may be almost twice the estimated cost of averting behavior (application of sunscreen).[65] To estimate benefits, the Title VI analysis relies on epidemiological studies, which incorporate averting behavior as currently practiced. Omission of future increases in averting behavior may nonetheless overstate the benefits of reduced emissions of ozone-depleting chemicals.[66] The analysis may understate the benefits, however, if individuals alter their behaviors in ways that could increase exposure or risk (e.g., sunbathing more frequently and/or for longer periods).[67]

[64] For example, volcanic eruptions increase dust levels, which may affect risks from stratospheric ozone depletion.

[65] Murdoch, James C. and Mark A. Thayer, "The Benefits of Reducing the Incidence of Nonmelanoma Skin Cancers: A Defensive Expenditures Approach," *Journal of Environmental Economics and Management*, 1990, pages 107-119.

[66] Although Dr. Marianne Berwick, an epidemiologist at Memorial Sloan-Kettering Cancer Center in New York, issued a study indicating that sunscreens are ineffective in preventing melanoma, many dermatologists contest this assertion ("Studies Doubt Sunscreens Stop a Cancer," *The New York Times*, February 2, 1998, page 19; Berwick , Marianne, *Sunscreens and Skin Cancer: The Epidemiological Evidence*, February 17, 1998; Boyd, Christopher, "Sunscreen Research Burns Up Skin Specialists: Doctors Fear Controversial Report Will Confuse Public," *Orlando Sentinel*, March 1, 1998, page A4).

[67] Autier *et al.*, 1999.

Table G-14
Major Limitations of Existing Benefits Analyses for Title VI

Limitations	Effects on Benefits Estimates
Scientists have an incomplete understanding of • the chemical and physical processes that cause ozone depletion, • the relationship between ozone depletion and exposure to ultraviolet radiation (UV-b), and • the dose-response coefficients relating UV-b exposure to melanoma skin cancer and cataracts.	A better understanding may either increase or decrease the benefits estimate.
Scientists have not yet developed quantified dose-response relationships for some benefits, such as reduced damage to the immune system from UV-b radiation.	Additional dose-response relationships will increase the benefits estimate.
The long term nature of the studies introduces a significant degree of uncertainty. For example, predicting innovation, research and development, producer and consumer responses to price changes, technological change, and major natural events for the next 100 to 150 years is difficult.	A better ability to forecast future events may either decrease or increase benefits estimates.
Although truncation of benefits and cost streams is necessary for the analysis, it does influence the size of the benefit and cost estimates.	The current method of truncating benefit and costs streams results in a greater underestimation of benefits than costs.
The RIAs do not account for averting behavior (i.e., people's efforts to protect themselves from UV-b radiation) or behavior increasing exposure or risk (e.g., increased sunbathing).	Inclusion of averting behavior may decrease the benefits estimate, while inclusion of enhancing behavior may increase the benefits estimate.
Not all RIAs for Title VI include comprehensively monetized benefits, due, in part, to key data gaps (e.g., accepted concentration response functions for ozone effects on forests).	More comprehensive monetization will increase the benefits estimate.
Section 608	
The extent of compliance with recycling rates mandated by the Venting Prohibition is very uncertain. Therefore, the baseline assumptions regarding the percentages of CFCs that are actually recycled are also very uncertain.	A better ability to forecast recycling rates may either decrease or increase benefits estimates.
The baseline recycling value assumes no innovation in recycling technologies through 2017, which may be inaccurate.	Including innovation in recycling technologies may increase the benefits estimate.
Section 611	
Manufacturers' and consumers' responses to labeling rules are difficult to predict.	An enhanced ability to forecast their responses may either increase or decrease the benefits estimate.
Benefits attributed to labeling regulations may actually result from other circumstances as well.	Consequently, the benefits resulting from this rule may be less than the estimate included in the RIA.
Although some sectors may reduce the use of MCF as a result of the labeling rule, other sectors may increase their use of this substance.	A better ability to predict people's actions may decrease the benefits estimate.

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